REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
Nov 94

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Bodly into the night: The development of the Naval Night Fighter

5. FUNDING NUMBERS

6. AUTHOR(S)
Lawrence Michael Gatti

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AFIT Students Attending:
Ohio State University

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/CI/CIA
94-141

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
DEPRTMENT OF THE AIR FORCE
AFIT/CI
2950 P STREET
WRIGHT-PATTERSON AFB OH 45433-7765

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release IAW 190-1
Distribution Unlimited
MICHAEL M. BRICKER, SMSgt, USAF
Chief Administration

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

19941207 066

14. SUBJECT TERMS

15. NUMBER OF PAGES
78

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

94-141

BOLDLY INTO THE NIGHT:

THE DEVELOPMENT OF THE NAVAL NIGHT FIGHTER

A Thesis

Presented in Partial Fulfillment of the Requirements for

the degree Master of Arts in the

Graduate School of The Ohio State University

by

Lawrence Michael Gatti, B. A.

* * * * *

The Ohio State University

1994

Master's Examination Committee:

John Guilmartin

C. Mark Grimsley

Margaret Newell

Approved by

Adviser

Department of History

To my late father, Lawrence A. "Al" Gatti

who fought in the Pacific Theater

ACKNOWLEDGMENTS

I express sincere thanks to Professor John Guilmartin for his insight and guidance throughout my research and writing. Thanks also go to Professor Mark Grimsley for his support and assistance and to Professor Margaret Newell for her advice. This thesis would not have been possible without the assistance of the Rebecca Livingston of the National Archives. I also thank my fellow military officers, Verb Washington and Ron Kyle, whose assistance and support were invaluable. Most importantly, I thank my wife Rebekah for providing unwavering support and understanding throughout this process.

VITA

September 27, 1957	Born - Youngstown, Ohio
1986	B.A., The Ohio State University, Columbus, Ohio
1986 - Present	Aircraft Maintenance Officer, United States Air Force

FIELDS OF STUDY

Major Field: History

Studies in Military History with Professor John Guilmartin, Professor Allan Millett, and Professor Mark Grimsley.

TABLE OF CONTENTS

INTRODUCTION

In 1941 the United States Navy was preparing for war against Japan in accordance with War Plan Orange. As tensions between the two countries increased, naval leaders recognized that the US Pacific Fleet would have to shoulder the burden of offensive and defensive operations in the Pacific. They also acknowledged that the Japanese Army and Navy air forces posed a serious threat to the safety of the US fleet. The Navy depended on the anti-aircraft batteries of the ships in the formation and fighter aircraft operating off carriers to defend the fleet during the day, but the fleet air defenses were inadequate if the enemy made a bomb and torpedo attack at night. As a result, in September 1941 the Navy issued a requirement for a carrier-based night fighter equipped with radar that could be used to intercept night attackers.[1] But this initiative posed a major problem: no radar set or

[1] Letter from BuAer to Director, NRL November 28, 1941, BuAer Secret Correspondence(now unclassified), National Archives, Record Group 19, Box 3.

aircraft, let alone a combination of the two, existed which could satisfy the requirement.

Compounding the Navy's problem in acquiring a carrier night fighter were the restrictions that the aircraft and carrier designs imposed on the fighter requirement. Only single-engined aircraft could operate off the carriers and only single-seat fighter designs promised the necessary margin of performance to adequately perform night intercepts. These restrictions dictated a light, compact and simple-to-operate radar system --technology which simply did not exist in 1941. The night fighter also had to have sufficient performance to accept the additional weight of the radar system without sacrificing acceleration or maneuverability; thus the Navy request entailed a demanding engine performance requirement in addition to the demanding electronic and aerodynamic requirements. The Navy tapped the combined resources of the Naval Research Laboratory, the Radiation Laboratory, and several civilian electronics firms to find a technological solution to these difficult requirements.

This combination of organizations proved effective, and in September 1943 the Navy fielded its first single-seat carrier night fighter. This achievement was an outstanding

example of innovation and cooperation between the civilian and military scientists and engineers at these various organizations.[2] These groups achieved in two years what no other country's research and development teams accomplished during the entire Second World War: they developed and fielded an operational, effective, single-seat, single-engine, carrier-based night fighter.[3] This remarkable success has not received as much attention as other similarly successful technological achievements such as the variable timed(VT) proximity fuze, the submarine, the long-range escort fighter, and the atomic bomb. Even the development of the turbojet engine, which had little significant impact on the course of the war, has received a

---

[2] While the close cooperation of civilian scientists and the military produced a number of successful innovations like those listed in the latter part of this section, close cooperation did not guarantee success. The torpedo, several Army fighter aircraft(including the XP-77), and the Navy's SB2C Helldiver dive bomber are examples of developmental failures despite intensive research and development work. Each of these programs exhibited poor communication of operational requirements by the military and impractical technological solutions by the scientist and manufacturers. Thus it cannot be assumed that close cooperation always existed between the scientists and the military, or that their collaboration was always fruitful.

[3] While neither the Germans nor the Japanese had specific requirements for a carrier-based night fighter, both needed single-seat aircraft with the capabilities of the American carrier night fighter. The German night fighters were twin-engined, multi-crew aircraft that had medium wave radar sets. The medium wave radar was less effective and the twin-engine design required a greater allocation of scarce resources. The Germans did not develop a microwave radar set until early 1945, and never produced them in significant numbers. The Japanese did not produce a night fighter until 1944 and it too was a land-based twin-engine, multi-crew aircraft with medium wave radar. Japanese radar sets were unreliable suffering from poor quality components. They developed a microwave set, but were unable to field any production units before the war's end.

great deal of attention because of its post-war importance. Like the turbojet engine, the carrier night fighter had little impact on the strategic course of the war, but had a profound impact on American fighter development and design after the war.

Historiography

Although the development of the carrier night fighter has not received principal attention in scholarly works, it has received peripheral attention in various literature. Gunston's, *Night Fighter: A Development & Combat History,* concentrates mainly on the development and employment of the British and German night fighters. Although he discusses the development of American land-based night fighters, he devotes only about three pages to the carrier-based night fighter. He also fails to relate the achievement to any larger issues. His supporting evidence is not particularly well documented. Gebhard Ader's *History of the German Night Fighter Force 1917-1945* offers a much better account of the development of radar and night fighter aircraft.[4] Ader also analyzes the failure of

---

[4] Gebhard Aders, Trans. by Alex Vanags-Baginski and Brendan Gallagher, *History of the German Night Fighter 1917-1945,* (London: Jane's Publishing Company, 1979).

the German night fighter program to halt the Allied night bombing effort. His work is well-supported and footnoted. Other historians including Samuel Morison, Clark Reynolds, and the Belote brothers mention a few of the night fighter operational successes in their naval histories, but none focus on its development.

While the carrier night fighter is not the subject of any single book, the most important component system of the night fighter, radar, has received a good deal of attention. Most of the works about radar focus on the British role in radar development. Several of the leading scientists and engineers involved with British radar development have chronicled their work. These first-hand accounts provide insight into the chronology and key people involved in developing and fielding British radar systems. By far the most satisfying of these are E.G. Bowen's *Radar Days* and Bernard Lovell's *Echoes of War: The Story of H_2S Radar.*[5] Both of these works combine a clear chronological account of the development of British airborne radar, with an analysis of the problems attending organizational and operational development. They also provide

[5] E.G. Bowen, *Radar Days*, (Bristol, UK: Adam Hilger, 1987). Bernard Lovell, *Echoes of War: The Story of H_2S Radar*, (Bristol, UK: Adam Hilger, 1991).

a wealth of detail about the British contribution which help to balance an American account of the early development of airborne radar. Bowen's book is less valuable because he tends to be more laudatory than analytical about the political and organizational problems that arose during the war. Both authors use official documents to complement their personal recollections of their work. One of the few accounts of American radar development is *Radar in World War II* by Henry E. Guerlac.[6] Guerlac, like Bowen and Lovell, provides a first-hand account of the work that he and his fellow scientists at the Radiation Laboratory at the Massachusetts Institute of Technology accomplished. Guerlac does not provide much analysis of the cooperation between the civilian scientists and the military as does Lovell. Guerlac covers every radar related device that the Radiation Laboratory developed, which accounts for the size of his two volume work which took him forty years to complete. Guerlac uses excellent supporting data that is also well documented, but this work is really a broad narrative.

Besides the first-hand accounts of radar development, several contemporary authors have analyzed the impact of radar

[6] Henry E. Guerlac, *The History of Modern Physics 1800-1950 Volume 8: Radar in World War II*, (Boston: American Institute of Physics, 1987).

development. David E. Fisher's *A Race on the Edge of Time: Radar--The Decisive Weapon of World War II* contends that radar was the single most important technical and military achievement "of them all, bar none."[7] But his assertion lacks solid analysis and support. His evidence is anecdotal and unconvincing. Conversely, Tony Devereux in his book, *Messenger Gods of Battle: Radio, Radar, Sonar: The Story of Electronics in War* takes the opposite approach.[8] Devereux maintains that radar like many other electronic devices developed during the war were contributory, but on a much smaller scale than generally perceived. His analysis also suffers from poor support documentation and the random organization of his arguments. While both these authors attempt to place radar and electronic developments in a larger strategic context, their arguments are not supported by solid data.

Expanding my review of literature to other technological innovations during the war revealed many books that were more celebratory in nature than analytical. But two books about

---

[7] David E. Fisher, *A Race on the Edge of Time: Radar--The Decisive Weapon of World War II*, (New York: McGraw-Hill, 1988.), xi. Edward W. Constant II, *The Origins of the Turbojet Revolution*, (Baltimore: The Johns Hopkins University Press, 1980),

[8] Tony Devereux, *Messenger Gods of Battle: Radio, Radar, Sonar: The Story of Electronics in War*, (London: Brasseys, 1991).

technology in World War Two stand out: Edward Constant's *The Origins of the Turbojet Revolution* and Charles M. Baily's *Faint Praise: American Tanks and Tank Destroyers during World War II*.[9] Both these works provide solid analysis of the key factors and problems in the development of the respective systems. Both weapon systems faced several technical and organizational obstacles and both authors provide good supporting evidence to support their arguments. They both highlight the important relationship between civilian scientists and military development organizations, both positive and negative. Constant explains how technological innovations, like the turbojet engine, represent an anomalous aspect in an otherwise incremental development of aircraft propulsion systems. Baily's book analyzes the failure of the American Army and research and development team to produce a successful tank in 1944 to replace the aging Sherman tank. These two monographs reveal the larger issues of the important relationship between science and the military during World War II in the context of a focused technical monograph.

---

[9] Edward W. Constant II, *The Origins of the Turbojet Revolution*, (Baltimore: The Johns Hopkins University Press, 1980). Charles M. Baily, *Faint Praise: American Tanks and Tank Destroyers during World War II*, (Hamden, CT: Archon Books, 1983).

My study of the development of the naval night fighter more closely resembles Baily's book, albeit on a much smaller scale. While Baily works with the negative argument of why Americans could not produce a better tank, my study looks at the successful technical solution to a tactical problem. This paper focuses on the development of the radar system that was the heart of the naval night fighter. The airframe and engine problems were, as it turned out, solved attendant to satisfying other Navy requirements. I will discuss the importance of the organization and mobilization of the American scientific community and the critical contributions of the British Technical Mission and how that mission spurred the development of microwave radar. My second chapter will detail the development of the two airborne intercept radar sets and how the research and development teams were able to overcome a multitude of technical problems to field the first carrier night fighters. My final chapter will evaluate the combat effectiveness of the carrier night fighters and the function and reliability of the airborne intercept radar systems. The task of developing the carrier night fighter in 1941 was daunting. That they met the challenge less than two years later is remarkable.

Chapter I

Organization and Impetus

The organization of American scientific resources and the contributions of the British Technical Mission were the keys to the success of the carrier night fighter development program. Integral to the success of this program was the development of microwave radar and its inherent advantages.

The development of airborne intercept radar began with the successful mobilization and organization of American scientific and production resources prior to the war. The most important catalyst was the creation of the National Defense Research Council(NDRC) in June 1940. The NDRC was the brainchild of Dr. Vannevar Bush, an inventor, businessman, electrical engineering professor and Chairman of the National Advisory Committee on Aeronautics(NACA).

Bush wanted to establish closer ties between civilian scientists and military scientists working on non-aeronautical projects like the NACA had done for aeronautical research and development. He used his considerable influence as NACA

Chairman to secure approval for the NDRC. Bush envisioned the Council as a body that would coordinate all aspects of scientific research (except aeronautical) in developing more potent military weapons. He viewed the harnessing of America's scientific potential as crucial to a quick and decisive victory.[10]

On June 27, 1940, President Roosevelt endorsed Bush's concept when he authorized the creation of the National Defense Research Council and signed the appointments of the primary representatives. Roosevelt selected Bush as Chairman and also asked the War and Navy Departments to provide members for the NDRC. The National Defense Research Council was directly responsible to the President. This was a "radical departure--a decision to put a large portion of military research under the control of civilians...."[11] Never before had the President taken the responsibility for military weapons development and placed it the hands of civilians directly under his control. Bush and the NDRC mobilized the finest scientific minds in America to develop weapons that would give the US every

---

[10] James Phinney Baxter III, *Scientists Against Time*, (Boston: Little, Brown & Company, 1946), 14.

[11] David Kite Allison, *New Eye for the Navy: The Origin of Radar at the Naval Research Laboratory*, (Washington: Government Printing Office, 1981), 155-156.

technological advantage. The organization of American scientists by the National Defense Research Council was one of the primary contributors to the rapid development of the radar and the other associated electronic components for the naval night fighter.

But the Navy research establishment, particularly the leaders of the Naval Research Laboratory, did not immediately embrace the concept of a civilian-dominated military research organization. The relationship between the Navy and the NDRC was very unsettled at this point. Admiral H.G. Bowen, who was the Navy representative to the committee, felt that the NDRC(and its Radiation Laboratory) would "...*supplant* instead of *supplement* the research activities of the Army and Navy."[12] Author David Kite Allison uncovered other evidence of Admiral Bowen's distrust of Bush and what the council's role would be after the war.

In response to the growing importance of the National Defense Research Council, Admiral Bowen attempted to create a Navy Research Bureau. Bowen proposed that the Research Bureau would control the direction of Navy research by consolidating research projects and funding under one bureau chief,

---

[12] Allison, 164. This is a quote from a letter from the NRL to the Secretary of the Navy via the Chief of Naval Operations.

presumably Bowen himself. Bowen believed that only the Navy could correctly decide which weapons research projects warranted the most funding and attention.

But the other Navy bureau chiefs did not support Bowen's plan. The chiefs of the various Navy bureaus controlled their research budgets and assigned projects to the Naval Research Laboratory along with the appropriate funding. They objected to having this responsibility taken away from them and assigning it to one man.

The General Board supported the Bureau chiefs position and rejected Admiral Bowen's idea in favor of creating an advisory position on the Chief of Naval Operations(CNO) staff. The General Board felt that the NDRC would be more successful in attracting the best scientific minds in the nation and would create a more dynamic research body. As a result of the General Board's decision, the NDRC would be the focus for wartime research. As it turned out the cooperation and division of labor between the agencies improved and significantly contributed to the success of the night fighter development program.[13]

---

[13] Allison, 167-169.

Having settled the roles the respective research organizations would fulfill, Secretary of the Navy Frank Knox decided to make further improvements to the Navy's research structure. He asked Dr. Jerome C. Hunsaker, Chairman of NACA(he had succeeded Bush), to conduct a study of the problems with Navy research. In a letter to Assistant Secretary of the Navy James V. Forrestal, Hunsaker recommended that the Secretary of the Navy create a position of "Coordinator of Research and Development." He also recommended that the Naval Research Laboratory be placed under the Bureau of Ships(BuShips). Secretary Knox issued General Order 150 on July 12, 1941 adopting these two Hunsaker recommendations. Knox persuaded Hunsaker, a 1908 Naval Academy graduate and head of the Aeronautical Engineering Department at MIT, to accept the position of Coordinator. Knox realized that Hunsaker's reputation as a prominent scientist would tighten the bond between the civilians at the Radiation Laboratory and the military scientists at the Naval Research Laboratory. Hunsaker's appointment to the key leadership position in Navy research was paramount for the close and complementary relationship that resulted between the two groups. This close

relationship was one of the reasons for the successful development of carrier night fighter.[14]

For the duration of the war, the National Defense Research Council and its Radiation Laboratory would be the primary military research organization and the Naval Research Laboratory would concentrate on solving the technological problems directly associated with Navy projects. The relationship between the civilians and the military began on shaky ground. But by the time America was at war the research communities would begin to gel into an impressive team.

[14] Allison, 172-173.

Radiation Laboratory

The team that concentrated on radar development was Division 14 of the Radiation Laboratory. On October 18, 1940, the National Defense Research Council's Microwave Committee authorized the creation of the Radiation Laboratory to be established at the Massachusetts Institute of Technology (MIT.)Bush desired to keep as many of the civilian scientists working in their own labs as possible, but he also realized that to accelerate radar development that a central laboratory would be necessary. His plan was facilitated by the fact that MIT was one of America's leading electrical engineering research centers and many of the leaders in the field were already working there.

Initially the military wanted to locate the laboratory at Bolling Field in Washington, DC which was also close to the Naval Research Laboratory at Bellvue. But at the last minute the committee decided it was wiser to keep the scientists at their own laboratories as much as possible rather than move everyone and lose time and cause personal disruption. The committee selected Dr. Lee A. DuBridge of the University of Rochester as the director. DuBridge was highly regarded in the field of radio wave research and Bush believed his selection

would lend prestige to the lab and help attract other leading scientists.[15]

DuBridge was able to attract some of the finest scientific minds from the fields of physics and electrical engineering. The Radiation Laboratory became the primary developer of all types of radar including airborne intercept radar. While housed in somewhat cramped facilities around the Massachusetts Institute of Technology, DuBridge's staff was able to produce an impressive number of radar and other electronic innovations during in a short time. To better appreciate the challenges that the scientists of Division 14 faced, a brief look at the state of American radar development is necessary.

Early American radar development

The radar system was the heart of the naval night fighter or indeed, any night fighter. Airborne intercept radar enabled the pilot to locate enemy aircraft and maintain contact until the night fighter was within gun range of the target. This paper will not describe in detail the scientific basis for radar.[16] The American scientists and engineers of the 1940s

---

[15] Allison, 158-159. Baxter, 21.

[16] The term "radar" is derived from Radio Detection and Ranging, the American name for radio detection. According to several sources, radar was

had to clear substantial hurdles in order to provide operational radar systems to naval aviation.

American radar research began in 1933 when the US Navy conducted experiments using radio waves to detect distant objects. Dr. A. Hoyt Taylor, Superintendent of the Naval Research Laboratory at Anacostia, District of Columbia, and engineers Leo C. Young, and Lawrence A. Hyland discovered that a passing plane had re-radiated radio waves that were intended for a receiver mounted in a parked aircraft several miles away. They expected that the passing plane would re-radiate the waves as the Hertz theory predicted. But they did not expect the waves reflected by the passing plane to be detectable to their receiver. Their discovery led to their development and patent of the "beat detection" system.[17]

While the Navy recognized the potential for using the "beat detection" system, tight military budgets precluded more funds from being channeled to Taylor's Naval Research Laboratory for its development. It was not until the Naval

---

coined by two Navy officers, Lieutenant Commanders S.M. Tucker and F.R. Furth in November 1940. The British used the name Radio Direction Finding(RDF) until adopting the American version in 1944. Sean.S. Swords, *Technical History of the Beginnings of Radar,* (London: Peter Peregrinus Ltd., 1986), 1.

[17]) Guerlac, 64-67. Beat detection refers to the sound of the minima and maxima of the reflected waves as heard on the audio receivers.

Research Laboratory developed the pulsed wave detection system that the Navy gave significant support to their research.

The new pulse system operated on the 200 Megahertz(MHz) frequency and the Navy mounted it on the destroyer *Leary* in 1938. This radar set was the prototype for the first privately produced American radar , the Radio Corporation of America's (RCA) CXAM radar set. The Navy had installed CXAM radar sets on most battleships and aircraft carriers by 1940.[18]

While the Navy conducted the majority of military radar research the Army also conducted research at their Signal Corps Laboratory at Fort Monmouth, New Jersey. The Army developed radar for use in providing ground forces with early warning of incoming enemy aircraft. The Army developed the SCR-270 and 271, a mobile and fixed system respectively, but like the early Navy shipborne radar sets, they were large, bulky, and not very reliable.[19]

While development of early warning radar continued steadily, neither service engaged in any research or development of an airborne radar system before 1940.[20] The

---

[18] Buford Rowland and William B. Boyd, *US Navy Bureau of Ordnance in World War II*, (Washington: Government Printing Office, 1954), 414.

[19] Guerlac 99-119.

[20] RCA had installed a rudimentary obstacle detection device in a Ford aircraft at Camden, New Jersey in January 1938. During the test flight

early warning radar systems weighed hundreds of pounds and used antennas that resembled large bedsprings. The challenge of reducing the size and weight of radar components to fit inside an aircraft kept American airborne radar research nonexistent. However, the British, who had already developed an airborne radar set and were already at war in Europe, provided the catalyst for the development of American airborne radar.

The Tizard Mission

In the history of the development of American airborne intercept radar the contributions of the British were essential. In September 1940 Sir Henry Tizard, noted British scientist, led the English Technical Mission to the United States. Commonly referred to as the Tizard Mission, the British leaders sent Tizard to the United States to collaborate on scientific research and development, but primarily to gain US help in producing vital radar sets.

The British had developed an airborne radar set and their Bristol Blenheim radar-equipped night fighters were already operational. But the British electronic industry could not

---

another aircraft was detected at about 3/8 of a mile. This is the first American airborne radar. Apparently neither the Army or Navy did any follow up of this experiment. Guerlac, 207.

produce the quantity or quality of radar sets to sustain Royal Air Force(RAF) night fighter operations. The British leaders realized that the US possessed a vast untapped research, development, and production potential. The purpose of the Tizard Mission was to share their advanced radar research in exchange for American development and production capability.[21]

The key member of the Tizard's Mission was E.G. "Taffy" Bowen. Bowen was the leader of the British airborne radar development team and was the chief architect of British airborne radar design. Bowen brought complete details of his team's airborne intercept radar development and shared them with the US Army and Navy. Admiral Harold G. Bowen, Director of the Naval Research Laboratory, was Bowen's key contact during this initial meeting. Both the Navy and Army shared their work on radar with the mission.

The quality of the US Navy's CXAM shipborne radar set surprised the British because it was similar in frequency and design to the British Chain Home Low(CHL) surface detection set.[22] But the lack of progress in airborne intercept radar

---

[21] Gunston, 59-67. Bowen, 145-150.

[22] The Chain Home Low system provided the British with early warning of German air attacks during the crucial Battle of Britain in September 1940. Many believe that the CHL system was instrumental in the British victory.

and air to surface vessel radar(ASV), and most importantly centimetric wavelength radar surprised them more. The Americans were woefully behind in any type of airborne radar development.[23]

The information provided by Bowen and the Tizard mission energized the moribund American airborne radar development. But the most important item that the Tizard Mission shared was not information, but a device. Bowen hand-carried a small piece of equipment that would revolutionize radar progress and would form the basis of the American night fighter program. That item was the resonant cavity magnetron, which produced centimetric wavelength energy.[24]

<u>The resonant cavity magnetron and microwave radar</u>

In both the United States and England scientists knew that a radar system using centimetric wavelength(microwave) would have many superior attributes. A microwave system would produce a narrower beam, which would give more accurate target bearing and elevation. Before 1940 none of the four known

---

[23] Bowen, 157-158.

[24] Centimetric radar has a wavelength of less than 50 cm. Americans refer to it as microwave. A wavelength and frequency chart is in Appendix A.

generating sources for centimetric waves were capable of producing enough power for any useful military application.[25]

British scientists at various universities had been working on devices that promised to deliver centimetric waves at sufficient power to be used in a radar set. At the University of Birmingham in England two physicists, J.T. Randall and H.A.H. Boot, abandoned the available methods for developing microwaves and developed a device using the Hertzian property of wave resonance. The device was the resonant cavity magnetron. Machined out of a solid copper billet, it resembled a cylinder from a revolver. The six concentric bores fed resonant energy into the central bore via slots one tenth of centimeter in diameter. The resonating waves in the center produced a higher output of radio wave energy. On February 21, 1940, Randall and Boot tested their magnetron and it produced 450 watts at a wavelength of 9.8 centimeters. This represented 20 times the power generated by the previous best magnetron, the Linder design magnetron that produced only 20 watts at 8

[25] Guerlac, 185-187. The four known sources of centimetric wave energy were: 1)spark gap transmitter, 2)Barkhausen-Kurz oscillator, 3)klystron, 4)split anode magnetron. The Americans also experimented with a device called a resnatron developed at Stanford and the University of California, Berkeley.

centimeters. Within a few months modified versions of Randall and Boot's design produced over 50 kilowatts.[26]

The development of the resonant cavity magnetron revolved around what Edward Constant calls a presumptive anomaly. In his book, *The Origins of the Turbojet Revolution*, he asserts that technology progresses within a traditional framework of received technology. He uses the example of the Rolls-Royce aircraft piston engine. The Rolls-Royce Eagle engine developed into the highly successful Merlin engine which in turn led to the powerful Griffon engine. This engine series improved as a result of technological advances that developed almost incrementally through the years.

But Constant states that the introduction of the turbojet engine represented a "presumptive anomaly" in the development of aircraft powerplants. The anomaly of a radical breakthrough, expected but unforeseen, that created a change in the received technology. He asserts that the breakthrough significantly alters the course of technology and produces an alternative path on which scientists and engineers can base further innovations.[27]

---

[26] Guerlac, 187-228. Bowen, 131. Gunston, 67. Swords, 258.

[27] Constant, 10-24.

Randall and Boot's resonant cavity magnetron was just such an anomaly. Their device differed radically from any existing design. Radar development had proceeded incrementally with small gains in transmitter power output and antenna and receiver sensitivity over the preceding three years. But the resonant cavity magnetron propelled radar development into the previously unreachable realm of microwave technology. It also pushed centimetric wavelength radar from scientific speculation to practical application within one year. Scientists knew that microwaves could be produced; the technology to do so was unknown until Randall and Boot tried a new device based on known scientific principle to solve the problem.

The invention of the resonant cavity magnetron was the pivotal point in the development of microwave radar. Among the many technological innovations that scientists created during the war only the harnessing of atomic energy represented a larger leap of technology.[28] Further underscoring the importance of the resonant cavity magnetron was the importance the Allied Combined Chiefs of Staff placed on protecting the device. A memo to the British and American Navy leaders stated:

---

[28] As Dr. Guilmartin has reminded to me, most of the weapons used during World War II were developed before the war.

> ...no magnetrons or valves capable of transmitting or receiving on frequencies above 600 Mc/s(microwaves) are permitted to be carried on any mission involving risk of capture...expect widespread deployment of (microwave) radar equipment 1 March 1943.[29]

The critical importance of the magnetron becomes more apparent when one realizes the many advantages of microwave radar over medium wavelength radar systems. Foremost of these was the increased accuracy of position and height detection. Because of the narrower beam of microwave radar, target location data was more exact resulting in a more accurate intercept course plot. Microwave radar's narrower beam also permitted a much more compact antenna design. The performance of the beam could be further enhanced by using a parabolic reflector to focus the beam. The engineers could encase the whole antenna system inside a fiberglass casing called a radome.

Engineers could house the transmitter components in a fiberglass pod faired into the wing. This was pod was called a nacelle. The radar nacelle was much more aerodynamic than the complex, externally-mounted "stag antler" antennas that the Germans used on their radar-equipped night fighters. The German night fighters had clumsy-looking antenna aerials

[29] Combined Chiefs of Staff Memo 133, December 13, 1942, BuAer General Correspondence File, National Archives, Record Group 72, Box 49.

projecting from the nose and wings exposing them to damage from wind blast and careless ground handling. They also exacted a high performance penalty: the antenna array on a Ju 88G-1 reduced its overall top speed by nearly 40 miles per hour. Comparatively, of Navy night fighters the F6F-3N lost only 16 miles per hour and the F6F-5N only 14 miles per hour with their radar pods installed.[30]

In addition to the aerodynamic advantages, microwave systems did not suffer from interference that caused problems in longer beamwidth systems. Swords states the true advantage of microwave over medium wave(meter wave) systems is:

> "All metric AI systems suffered from the disadvantage that, because of the necessarily broad beamwidths of the antennae, strong ground return echoes were obtained, this meant that detection becomes impossible at ranges less than the height of the aircraft above the ground."[31]

Microwave radar was also more resistant to passive signal jamming. Later in the war both sides discovered that aluminum foil strips cut to one-half the length of the of the radar's operating wavelength caused a lot of interference on the radar scope. The Allies code named this passive jamming system

---

[30] William Green, *Famous Fighters of the Second World War, Volume Two*, (New York: Doubleday and Company, 1962), 64,111. Eric Melrose Brown, *Duels in the Sky: World War II Naval Aircraft in Combat*, (Annapolis: Naval Institute Press, 1988), 167.

[31] Swords, 252.

"Window." Microwave was not as vulnerable to this method of jamming, thus offering yet another advantage over the non-microwave systems. Microwave also proved to be more resistant to active jamming transmissions because the enemy did not possess equipment capable of transmitting on the microwave frequencies which were necessary for jamming operations.[32]

[32] BuAer Engineering Division History, Radio and Electronics Branch, Part 7C, 4, National Archives, BuAer files, Record Group 72, Box 3.

Chapter II

Airborne Radar Development

Utilizing the British magnetron and radar data, American scientists and engineers developed the first microwave radar set. Close cooperation between the Navy, Radiation Laboratory scientists, and contractor engineers was the hallmark of the development of the first American microwave airborne intercept radar. Despite numerous technical problems, this team was able to field the first carrier night fighter to meet urgent Navy operational needs.

The initial progress in the development of an American microwave set was hastened by the British scientist Taffy Bowen. Bowen organized the preliminary research on airborne intercept radar at the Radiation Laboratory by suggesting a preliminary organization that resembled the British organization. Using his experience in developing the British airborne radar research and development form scratch he provided a technical outline of suggested avenues of research. Bowen's assistance greatly accelerated the development of

airborne intercept radar by eliminating the usual preliminary organization and prioritization problems.

Bowen also helped to assign the distribution of contractor assignments for the initial development of the 10 cm airborne intercept radar. The primary contractors were Bell Laboratories, General Electric, Westinghouse, Sperry Gyroscope and RCA. Each contractor was given a 30 day deadline to produce the first five examples of their assigned components. The short deadline and the assignment of the component development to private firms were keys to the Radiation Laboratory's success in quickly developing the first workable model of microwave radar. Taffy Bowen's extensive experience developing British airborne intercept radar was invaluable in directing the focus of the Radiation Laboratory's early radar development.[33]

All the contractors delivered their components on schedule. As a result of this the Radiation Laboratory produced the first prototype 10 cm airborne intercept radar set in December 1940 and installed it in a Consolidated PBY twin-engine patrol bomber. The first radar set that the Radiation Laboratory constructed suffered from engine ignition

[33] Guerlac, 257-260.

interference due to faulty coaxial cables. The magnetron and receiver were also not properly tuned to the same frequency. But the most troublesome problem was the klystron antenna buffer which protected the receiver crystal from being damaged by transmission pulses. The klystron also created too much signal noise that consequently degraded receiver performance substantially. Despite the relatively poor performance of their first product, it was clear that the combination of scientific and engineering resources available would be able to overcome the problems and produce a workable microwave radar set.

E.G. Bowen and the Telecommunications Research Establishment(TRE, the Radiation Laboratory's British counterpart) helped to solve these problems. Early in 1941, R.W. Sutton of the ASE Company in Portsmouth, England designed a tube that used a rhumbatron sandwiched between two copper disks. Sutton's tube produced more power while creating very little interference noise. Radiation Laboratory engineers installed the Sutton "soft tube" in the first 10 cm radar set and cured the buffer problem. [34]

---

[34] Guerlac, 233.

In June 1941, the Radiation Laboratory solved the persisting mating problem between the transmitter and the receiver by mating the more powerful American transmitter with the British 10 cm airborne intercept radar receiver. The marriage of the two combined with the British crystal mixer and Sutton "soft tube" resulted in a functional 10 cm radar set. On September 26, 1941 the D-M Section(model shop of Radiation Laboratory) contracted with the Research Corporation of New York to produce field evaluation prototypes of the 10 cm set. The continued teamwork between the British and Americans was essential during the early development of the microwave set.[35]

As work on the 10 cm set progressed in early spring 1941, the Raytheon Company, working closely with the scientists at the Radiation Laboratory, produced a magnetron that operated on the 3 cm frequency. Even though the problems posed by the 10 cm wavelength set were still formidable, the Radiation Laboratory physicist I.I. Rabi realized the potential advantages of developing a set built on this frequency. The smaller wavelength would provide an even narrower beam with even greater accuracy in target elevation and azimuth. The Bureau of Aeronautics became interested in the potential of the

[35] Guerlac, 272-287. These sets evolved into Army SCR-520/720 AI radar built by Bell Labs and the Navy AN/APS-2 ASV radar.

3 cm set to meet the need for the new night fighter requirement. The independent work of the Raytheon engineers had advanced the development of microwave radar which would be instrumental in the naval night fighter. It also proved the value of the close cooperation that existed between the various research agencies.

The Navy Bureau of Aeronautics(BuAer) was interested in the potential of 3 cm radar because it could provide not only air interception data but also the potential for blind gun-aiming information for a carrier night fighter.[36] In September 1941 BuAer requested that a lightweight 3 cm set be built for a powerful carrier-based plane then under development, the F4U-1. This marked the beginning of the development of the carrier night fighter.

The Navy submitted a stringent list of requirements for the night fighter radar set. The set had to weigh less than 250 pounds, have a small low aerodynamic drag antenna, and provide blind gun-aiming. The range requirements for the 3 cm set were two miles above 2000 feet maximum and a 500 foot minimum range.[37] On November 28, 1941, BuAer also requested

---

[36] Blind gun-aiming would enable a pilot to fire his guns at a target based solely on radar scope data with no visual cues.

[37] Guerlac, 342.

that the Naval Research Laboratory supplement the Radiation Laboratory's airborne intercept radar research to develop a system above 500 MHz for use on a single-seat, single-engine carrier fighter.[38]

The Navy's stringent requirements demanded an intensive cooperation between research agencies, and the relationship between the different organizations improved as the threat of war increased the urgency of their work. Rabi and project engineer J. Halpern were the leaders of the Radiation Laboratory team that began development on the experimental 3 cm radar model identified as CXBJ. They worked closely with the engineers at Sperry Gyroscope and the Naval Research Laboratory to design the world's first microwave airborne intercept set.[39]

Development of airborne intercept radar set AIA

The events of December 7, 1941 dramatically changed the urgency and emphasis on airborne radar research. Congress increased research budgets and the staff at the Radiation Laboratory doubled in size. The research and development budget for the Navy jumped from 8.9 million dollars in 1940 to

[38]. Letter from BuAer to Director, NRL November 28, 1941, BuAer Secret Correspondence(now unclassified), National Archives, Record Group 19, Box 3

[39] Guerlac, 342-343.

26.3 million dollars in 1941 and to 47.8 million dollars in 1942.[40]

The increase in funds and staffing did not begin to solve all the problems facing Rabi and Halpern in designing and building the airborne intercept radar. The set had to fit a single-engine, single-seat fighter with precious little room for any additional equipment in the cockpit or fuselage. Rabi and his team determined that a radar set mounted in a pod slung under the wing would be feasible. Halpern's design incorporated the new concept of using flexible metal waveguides to transfer the radio frequency(RF) energy from the magnetron to the rotable directional antenna(also called scanner or paraboloid).

The complexity of the CXBJ airborne intercept radar and the nature of the immature technology combined to slow its development and that of the pre-production radar set designated by the Navy as XAIA. It was not until June 1942 that Halpern's team was able to produce the experimental airborne radar set. Anticipating the same problems with the pre-production sets,

[40] *The History of United States Naval Research and Development in World War II*, unpublished copy of report compiled by the University of Pittsburgh Historical Staff at Office of Naval Research, Navy Operational Archives, World War II Command File, Box 374, 144.

they also assisted the Sperry Gyroscope engineers in building the first two XAIA's in September and October 1942.

Among the many problems the first sets exhibited were broken waveguides, automatic frequency control failures, and mechanical difficulties with the XAIA installation on the aircraft. The set was also 44.6 pounds over the specified weight of 135 pounds. Servicing the equipment also proved very difficult and it also did not fit properly in the Mark 51 Model 7 bomb rack of the SB2C-1 Curtiss Helldiver test aircraft. Despite the early problems Sperry delivered 10 early production sets to the Navy in April 1943. The Navy had finally received the first airborne intercept radar sets and the Bureau of Aeronautics requested that a night fighter squadron be established to integrate the radar systems with the airframes and develop night fighter training and tactics.[41]

Airborne intercept radar integration and Project Affirm

On April 18, 1942, the Chief of Naval Operations directed that the initial night fighter development unit be established at Quonset Point Naval Air Station, Rhode Island. The Bureau

[41] Letter from Chief BuAer to Commanding Officer Patuxent River Naval Air Station, October 22, 1943, and Letter from Director Naval Research Laboratory to Chief BuShips, October 21, 1943, BuShips General Correspondence, National Archives, Record Group 19, Box 60.

of Aeronautics directed the creation of the first Navy night fighter squadron, Night Fighter Squadron 75(VF(N)-75.) The Navy appointed Commander W.E.G. Taylor as the commanding officer of Project Argus which included VF(N)-75. But because there was another project at Quonset using that name, it was changed to Project Affirm on August 11, 1942. "Affirm" personnel were responsible for the initial tactical development of carrier-based night fighters.[42]

It would be appropriate at this point to introduce the two aircraft that became carrier night fighters, the F4U-2 Corsair and the F6F-3/5N Hellcat. The system had to be mounted on a capable fighter in order to fulfill its mission to defend the fleet at sea. As mentioned earlier in this paper, only single-engine aircraft could operate off carriers. In 1942 there were no multi-engine carrier aircraft in service(the Grumman F7F Tigercat, a twin-engine fighter was in initial planning and development). This dictated that the radar had to be pod mounted since the engine occupied the space in front of the pilot. The Navy, probably accepting E.G. Bowen's advice about the need for adequate speed and firepower in British night fighters, realized that their night fighter would have to

[42] BuAer Engineering Division History, Radio and Electronics Branch, Part 7A, 38, National Archives, BuAer files, Record Group 72, Box 3.

be a single seat fighter that had superb performance. There were no multi-seat aircraft with sufficient performance to warrant consideration. This line of thinking produced the decision to mount the lightweight microwave radar in a pod slung under the wing or faired into a wing nacelle of the best existing design, the Chance Vought F4U-1 Corsair.

The Corsair was a powerfully built and speedy fighter. It had an excellent rate of climb and was ruggedly built. But it suffered from several developmental problems that delayed the first night fighters use on aircraft carriers. Foremost of these was the poor forward visibility and deck landing characteristics. These deficiencies prevented the Navy from operating the Corsairs off carriers until Chance Vought and Navy engineers were able to solve these problems in early 1944.[43]

Because of they could not use night fighter Corsairs on carriers, the Navy urged Grumman to provide an updated F4F Wildcat design, using a more powerful R-2800 engine, to become the carrier night fighter. Grumman, in one of the most remarkable engineering and production feats of the war, produced the F6F-3 Hellcat in under 18 months. The Hellcat had

[43] VF Design Branch History, 67, BuAer Engineering Division History, Part 13, National Archives, Record Group 72, Box 5.

nearly the same performance as the Corsair but with none of the drawbacks. The first radar-equipped Hellcats began carrier operations with the fleet just one month after the Corsairs, despite having started development four years later. Grumman produced 1,189 night Hellcats, making it the most numerous American night fighter of the war.[44]

When the first Sperry radar sets arrived at Quonset Point, Project Affirm technicians installed production sets numbers two through seven on F4U-2's at Quonset Point NAS, Rhode Island. In December 1942, the Naval Aircraft Factory in Philadelphia had modified 37 F4U-1A's to the F4U-2 configuration which could accept the radar sets. These were the US Navy's first night fighters.[45]

The members of Project Affirm did the majority of their work preparing the radar sets and mounting them on the VF(N)-75 Corsairs for deployment. The Navy redesignated the AIA airborne intercept radar as AN/APS-4. Technicians mounted the radar set on the outboard bomb rack on the right wing. Engineers placed the radar on the outboard station because it

---

[44] VF Design Branch History, 87-89, BuAer Engineering Division History, Part 13, National Archives, Record Group 72, Box 5.

[45] Letter from BuAer to BuShips, March 25, 1944, BuShips General Correspondence, National Archives, Record Group 19, Box 146.

was believed that the if the beam was projected through the propeller arc that radar performance might suffer. Later, engineers found this to be false when they tested the radar on a Hellcat prototype aircraft.[46]

The engineers from Sperry, Radiation Laboratory, and the Naval Research Laboratory and Project Affirm were under pressure to prepare the Corsair night fighter for early deployment to the Pacific Fleet. Project Affirm engineers, working in conjunction with Radiation Laboratory and Sperry engineers responded to the many reliability and waveguide problems that arose during the first radar test flights. Engineers from the Radiation Laboratory and Sperry were able to solve most of the immediate radar problems, but Project Affirm engineers still had to integrate the radar set into the aircraft to ensure reliability.[47]

One of the first steps was to maintain proper aircraft balance. Project Affirm technicians removed two of the starboard .50 caliber machine guns to offset the additional weight of the radar pod to preserve the aircraft handling

---

[46] Letter from BuAer to BuShips, March 25, 1944, BuShips General Correspondence, National Archives, Record Group 19, Box 146.

[47] BuAer Engineering Division History, Radio and Electronics Branch, Part 7A, 38-39, National Archives, Record Group 72, Box 3.

characteristics. They added an autopilot control to ease the flying burden on the pilot while he was operating the radar tuning and gain controls(the only two adjustments the pilot could make).[48] The first night fighters completed by Project Affirm were assigned to VF(N)-75.)[49]

Unfortunately radar problems continued to plague these first aircraft during testing at Quonset Point. The primary weakness of the AN/APS-4 radar was the very long waveguide it used to transfer radio frequency(RF) energy from the magnetron in the fuselage to the scanner pod under the wing. The waveguide was subject to vibration and shock which often resulted in a cracking failure of the waveguide. Vibration also caused many of the tubes to become loose in their sockets. Moisture intrusion also caused shorting and the laminated plywood radomes covering the scanners absorbed too much transmitted energy.[50]

[48] Green, 85.

[49] Letter from Chief BuAer to Commanding Officer Patuxent River Naval Air Station October 22, 1943 and Letter from Director NRL to Chief BuShips October 21, 1943, National Archives, BuShips Radio Division General Correspondence, Record Group 19, Box 60.

[50] Letter from Chief BuAer to Chief BuShips, December 6, 1943, National Archives, BuShips General Correspondence, Radio Division, Record Group 19, Box 60. BuAer files, National Archives, BuAer Radar Section History, 30, BuAer Engineering Division History, Radio and Electronics Branch, Part 7C, Record Group 72, Box 3.

Despite the problems that the AN/APS-4 system exhibited, the Bureau of Aeronautics was willing to accept unreliable automatic frequency control performance and other deficiencies to accelerate delivery to the field. The Bureau of Aeronautics emphasized the pressing need for their operational deployment in a message stating:

> "This equipment[AN/APS-4] is of such value to the bureau that it does not desire to hold up production at this time....The weight will be reduced in production ASAP[as soon as possible], but NLT 1 May 44....A new double mixer AFC will be introduced in production ASAP."[51]

Through the intense efforts by the research staff and production agencies the first echelon of VF(N)-75 arrived at Naval Air Station Alameda, California in August of 1943. After further training they flew to Munda airstrip in New Georgia on September 23, 1943 to begin combat operations.

Project Affirm had succeeded in integrating, testing, and training the initial cadre of night fighter aviators. On September 20, 1943 the Bureau of Aeronautics requested dissolution of the project and the Chief of Naval Operations approved this request on October 26, 1943. Engineers moved to

---

[51] Letter from BuAer to BuShips October 4, 1943, BuShips Electronics Division, General Correspondence, National Archives, Record Group 19, Box 146.

Patuxent River Naval Air Station, Maryland to continue the testing of airborne intercept radar and night fighters.[52]

Development of the airborne intercept radar AIA-1

While the deployment of the AN/APS-4 equipped aircraft was imminent, the problems with the radar set prompted the Navy to order a product design improvement on March 16, 1943. The impetus for this decision was the early installation difficulties observed with the AN/APS-4, and especially the waveguide problem. Also the Navy required that the new set, called AIA-1, operate at the higher altitude of 30,000 feet and incorporate the recently developed higher-powered 3 cm pulse transformer. The pulse transformer was much more compact and could be mounted directly behind the paraboloid. This new arrangement, called the RF head, was first used in the prototype ASD-1(later AN/APS-3)airborne surface vessel radar set developed by Philco Company of Philadelphia. The RF head eliminated the need for the long waveguide, which promised to substantially improve the reliability of the system.

On June 14, 1943, the Radiation Laboratory selected Westinghouse Electric and Manufacturing Company to produce the

---

[52] BuAer Engineering Division History, Radio and Electronic Branch, Part 7A, 39, National Archives, Record Group 72, Box 3.

new airborne radar set. Radiation Laboratory project engineer R.M. Alexander and his team completed the first experimental set, designated XAIA-1, in September 1943. Alexander's Radiation Laboratory team had several problems with the antenna system. Alexander assisted Westinghouse engineers in completing the first pre-production set on December 1, 1943.[53]

The newest airborne intercept radar system was smaller than AN/APS-4 and consisted of only nine main components. The scanner unit with the transmitter/converter unit(RF head) and a signal junction box would be housed in a nacelle in the right wing. The receiver/amplifier, power rectifier, and the pulse modulator units were mounted in the equipment bay just behind the pilot seat(often referred to as the turtleback). The indicator scope(a plan position indicator type which displayed bearing and distance on one scope) along with the main and auxiliary control units were in the cockpit.

The system design looked promising but the Westinghouse designed RF head did not perform properly. Without the RF head the new radar would be useless. In a conference between the Navy, the Radiation Laboratory and Westinghouse on October 2, 1943 the Navy decided that the best scientists and engineers at

[53] Guerlac, 345.

the Radiation Laboratory and Westinghouse must be put on the project to solve the RF head problem. In particular the Navy representative emphasized the confidence he had in the Radiation Laboratory personnel to solve this problem. Alexander and his group devised an interim solution to the problem by mating a non-pressurized RF head from the Philco AN/APS-3 to the AIA-1(redesignated AN/APS-6) scanner.[54]

The Bureau of Aeronautics responded to pressure from the fleet for a better radar set for the night fighters and sent a letter to Chief of the Bureau of Ships stating:

> "In order to expedite deliveries of AN/APS-6 radar, BuAer has agreed to accept the initial equipments, not to exceed 150,...with the Philco AN/APS-3 transmitter/converter[RF head] instead of the Westinghouse pressurized unit."

The Philco RF head would limit service ceiling of the AN/APS-6A(modified unit designation) to 20,000 feet because it was unpressurized. But all other performance criteria could be met with the adapted RF head.[55]

---

[54] Conference Report, October 2, 1943, BuAer Confidential Correspondence(now unclassified), National Archives, Record Group 72, Box 829.

[55] Conference Report October 2, 1943 and letter from BuAer to BuShips October 20, 1943, National Archives, BuAer Confidential Correspondence(now unclassified), Record Group 72, Box 829. Guerlac, 345.

Westinghouse also had difficulty in obtaining reliable performance from the automatic frequency control(AFC) for the search and beacon modes.[56] The automatic frequency control function was critical for a single-seat fighter because the pilot could not divert his attention from flying to tune the proper frequency. No other airborne radar set in existence had an automatic frequency control which illustrates the innovative nature of the Radiation Laboratory design. The automatic frequency control permitted the pilot to fly a radar intercept without having to constantly fine tune and adjust his radar receiver. BuAer emphasized the urgent tactical need for this feature and demanded that Westinghouse put their best people on the problem to minimize the delay.[57]

Initial attempts by Westinghouse to solve the automatic frequency control problems using a motor-driven system proved unusable. The Radiation Laboratory and Westinghouse engineers teamed up to finally solve the automatic frequency control problem by eliminating "leakage" in circuit components. While not completely solving the automatic frequency control problems

---

[56] Beacon mode is a navigational aid for radar equipped aircraft. This feature was very important to a naval aviator trying to navigate to his carrier at night and over water.

[57] Letter from BuAer to BuShips, November 16, 1943, National Archives, BuAer Confidential Correspondence(now unclassified), Record Group 72, Box 829.

they were able to make it more reliable without major modifications. Shipboard electronic technicians could install the new circuit components thus improving operational reliability without sacrificing combat capability.[58]

In January 1944 the Radiation Laboratory team was able to improve the important beacon mode performance by using a "video stretching circuit" and potentiometer for limiting the beacon's local oscillator sweep voltage. These modifications provided pilots with better signal picture on the indicator when they used beacon mode. Radio Corporation of America, General Electric, and Radiation Laboratory engineers also worked closely on making improvements on the cathode ray tube indicator using long persistence phosphorous to also improve the visual target indication to the pilot. Thus the combination of Navy pressure and government and contractor cooperation was able to solve the initial shortcomings of the AN/APS-6(A) radar.[59]

But the antenna problems persisted, so Navy engineers at Patuxent River modified the antenna feed by twisting it 90

[58] BuAer Engineering Division History, Radio and Electronics Branch, Part 7C, 8-10, National Archives, Record Group 72, Box 3.

[59] BuAer Engineering Division History, Radio and Electronics Branch, Part 7C, 9-10, National Archives, Record Group 72, Box 3.

degrees. This improved reception in the azimuth axis, while this did not solve all the problems with the antenna, it did improve intercept resolution. The Bureau of Aeronautics sent letters directly to the antenna subcontractors to expedite delivery of a better and more reliable antenna for the AN/APS-6(A) radar set. The direct pressure by the Navy on the subcontractors was successful in expediting design improvements on the critical antenna component.[60]

By June 1944 AN/APS-6 radar set production had reached 50 units per month. This improved every month and by November 1944 production reached 150 units. At that time the Navy had enough radar sets to install in Hellcats as well as provide complete spare sets to the fleet. In November 1944 the Bureau of Aeronautics' Engineering Division requested a production cutback from the projected 250 units per month to the current 150 units per month. The production capability of Westinghouse and its subcontractors illustrated the outstanding response by industry to meet Navy demands, despite the technical

[60] BuAer Technical Report, NAS Patuxent River, 37452.5, National Archives, Record Group 72, Box 22.

difficulties in producing the complex airborne intercept radar equipment.[61]

The Pacific fleet continued to press for more and better radar-equipped night fighters. The Navy decided to replace Corsairs and Hellcats equipped with the first airborne intercept radar, AN/APS-4 with the newer set as soon as possible. As a result of this decision the first AN/APS-6(A) radar sets were installed on F6F-5N Hellcat fighters in May of 1944.[62]

The development of the two airborne intercept radar systems clearly illustrates the cooperative nature of the program. In every phase of the development the Radiation Laboratory scientists and engineers acted as a "brain trust" for the Navy and their civilian contractors. It was common for Radiation Laboratory personnel to work side by side with Sperry, Bell, and Westinghouse engineers to solve the many technical problems that the new microwave radar technology presented. The solid success of the Radiation Laboratory in

[61] BuAer Memo for Engineering Division to Production Division, November 13, 1944, BuAer Confidential Correspondence File, National Archives, Record Group 72, Box 830.

[62] Message from Chief BuAer to ComAirPac and ComFair Quonset, April 12, 1944, BuAer General Correspondence File, National Archives, Record Group 72, Box 1454.

developing a usable airborne intercept microwave radar system represents only one aspect of the night fighter program.

Airborne intercept radar sets adapted to a capable fighter airframe design were the two main factors in developing the carrier night fighter. But there were also some very important ancillary equipment developments that also enhanced the aircraft's capability. Naval Research Laboratory engineers developed red instrument lighting and tinted radar scope covers to prevent the bright light of the flight instruments and the radar cathode ray tube from ruining the pilots' night vision. The Navy Bureau of Ordnance engineers developed Stellite gun barrel linings which improved the durability of the .50 caliber machine gun barrel and permitted pilots to shoot longer bursts of fire without danger of overheating the barrel. The Airborne Radio and Radar Laboratory developed dual UHF and VHF radio sets to increase the margin of safety for the night aviator by providing a backup radio in case of main radio failure. All of these improvements were cooperative ventures with aircraft and electronics contractors. This equipment enabled the night fighter aviator to better perform the difficult mission of flying and fighting in the dark.[63]

---

[63] Letter from BuAer to BuShips, March 25, 1944, BuShips General Correspondence File, National Archives, Record Group 19, Box 146. BuAer

Identification Friend or Foe(IFF) system development

The most important ancillary equipment item that the Radiation Laboratory and the Naval Research Laboratory developed was a device that identified the target on the night fighter's radar scope as an enemy target--the Identification Friend or Foe(IFF) system.

The British had initially developed the first radar identification system. Soon after the US entered the war the Chief of Naval Operations recognized the immediate need for such an identification system for naval aircraft. The afternoon of December 7, 1941 nervous Army anti-aircraft gunners shot down several Navy Wildcats. Naval Intelligence also received reports that the Japanese bombers had horizontal stripes painted on the fuselage in an attempt to confuse American fighters. The Navy also acknowledged that the identification system had to be compatible with other Allied aircraft.[64]

Technical Memo, March 6, 1944, BuAer General Correspondence File, National Archives, Record Group 72, Box 1481. Rowland and Boyd, 333, 345.

[64] Letter from Chief of Naval Operations to Chief BuShips, May 2, 1942 and Letter from BuAer to BuShips, March 23, 1942, BuAer General Correspondence File, National Archives, Record Group 72, Box 49.

The Radiation Laboratory and the Naval Research Laboratory developed an identification system that used coded pulse transmissions to shipboard receivers. The system, called ABA, that the Radiation Laboratory was developing was superior to the simpler British Mark III system. But because the American system components would not fit into all the British aircraft the Chief of Naval Operations and Chief of the Bureau of Aeronautics decided to procure the British Mark II systems as an interim solution until adequate amounts of the more advanced British Mark III system became available. The Americans and British decided to keep the American ABA identification system as a backup in case the British Mark III system became compromised.[65]

The Mark III identification system was not reliable and Navy pilots did not trust it. Numerous system failures and false indications were the principle reasons for their distrust. The Radiation Laboratory and the Naval Research Laboratory developed a modification that was compatible with the British Mark III identification system. The modification, code named "Black Maria," added an additional pulse

[65] Letter from Chief of Naval Research Laboratory to Chief BuShips, April 30, 1942, BuAer General Correspondence File, National Archives, Record Group 72, Box 49.

transmission on a separate frequency range to make the system more reliable and trustworthy.

When the night fighters arrived in the Pacific for combat duty they represented a substantial investment of scientific and production resources. The complex and sophisticated airborne intercept radar system and the rest of the specialized night fighter equipment was developed and produced in under two years. But as I indicated in the introduction, a weapon system is only as good as its performance in combat.

Chapter III

Operational Analysis

The prominent British scientist Sir Solly Zuckerman noted, in the context of development programs like the carrier night fighter, that "Weapons can be evaluated only through an analysis of actual operations."[66] His statement indicates that the carrier night fighter program must be judged not only by its impressive technological composition but by its usefulness as a military weapon. The performance of the night fighter and its systems was the final test in its development.

The Navy deployed the first combat night fighter squadron flying F4U-2 Corsairs to Munda, New Georgia on September 23, 1943. The Corsairs could not be used off carriers yet, but they served as land-based night fighters to protect the troops on Guadalcanal from enemy night air attacks. The Corsairs, with their AN/APS-4 radar and good performance, made their first score on November 1, 1943 when Vella Lavella ground radar

[66] Solly Zuckerman, *Scientists and War: The Impact of Science on Military and Civil Affairs*, (New York: Harper & Row, 1967), 20.

vectored Lieutenant H.D. O'Neill to a target off the northwest tip of the island.[67] O'Neill made visual contact around 2200 hours. On his first pass he overshot his target but was able to reacquire the Japanese twin-engine bomber and shot it down. This was the first kill for a Navy night fighter.[68]

VF(N)-75 chalked up three more kills in December 1943 and January 1944. The radar-equipped Corsairs were able to do the job when their radar worked properly and the ground control intercept radar controllers were able to put the night fighter in position to acquire the target on his radar. VF(N)-75 had quickly proven the value of the night fighter. The squadron collected seven confirmed kills while flying 977 combat hours in just four months.[69] As enemy operations in the area began to dwindle, the need for a carrier-based night fighter became imperative as the fleet. It also became obvious that improved training for ground control intercept operators was necessary to ensure that the night fighters were able to make timely intercepts.

---

[67] Note: Naval Aircraft Action Reports used the designation AIA for all AI sets, these were AN/APS-4 sets.

[68] Aircraft Action Report, VF(N)-75, November 1, 1943, Naval Operational Archives, Night Aviation Operations File, Box 1.

[69] David Alan Rosenberg, "The Black Chickens: The Story of the Pioneer Navy Night Fighter Squadrons in World War Two", (Undergraduate composition, American University, 1967), 14.

But the land-based Corsairs were unable to provide the fleet with night air defense during the Gilbert and Marshall Islands campaign. Japanese night attacks had become an even graver threat to the security of the American naval forces. On December 4, 1943, Japanese torpedo planes using the illumination of four parachute flares managed to slip through the anti-aircraft fire of Admiral Charles A. Pownall's Task Group 50 and torpedo the *Lexington*.

The increased Japanese night attack threat forced the Navy to hastily certify the Corsairs for carrier duty. In January 1944 Admiral Marc A. Mitscher, who had replaced Pownall, took command of the fast carriers, redesignated Task Force(TF) 58. Included in his task force's complement were elements of the first carrier-based night fighters. VF(N)-76 flying night Corsairs and VF(N)-101 flying the newly arrived night Hellcats. Mitscher organized his night fighters into five detachments of four planes each to provide night air defenses for his fleet.[70]

On the night of February 17, 1944, the Japanese attacked Task Force 58. The inexperienced night Hellcat pilots

[70] Samuel Eliot Morison, *History of United States Naval Operations in World War Two, Volume VII, Aleutians, Gilberts and Marshalls*, (Boston: Little, Brown and Company, 1951), 352-353.

scrambled too late and they were unable to intercept the enemy attack. The Japanese torpedo planes heavily damaged the carrier *Intrepid*, forcing it to retire to Pearl Harbor for repairs. As one night aviator commented in his after action report, a night fighter needed adequate notice and accurate target information to make a successful intercept. He also commented that more training was necessary for the night aviator to maximize the benefit of his airborne intercept radar.[71]

Following the attack on the *Intrepid*, the night fighters operated in a variety of day combat air patrol and attack roles during the Truk and Hollandia amphibious landings. But using night fighters in day fighter roles rankled the newly trained night pilots who felt that their specially equipped mounts should be used for the missions for which they were intended. Lieutenant Reiserer in his April 20,1944 action report stated that "...AIA equipped planes are too valuable to be used for daylight work over enemy territory."[72]

---

[71] James H. Belote and William H. Belote, *Titans of the Seas: The Development and Operations of Japanese and American Carrier Task Forces During World War II*, (New York: Harper & Row, 1975), 264.

[72] Aircraft Action Report, VF(N)-76 aboard USS *Hornet*, April 20, 1944, Naval Operational Archives, Night Aviation Operations File, Box 1.

One of the more experience night fighter aviators, Commander Aurand of VF(N)-76, believed that as his squadron gained experience they would become more valuable to the fleet. He made several observations about his squadron's experience in their initial carrier operations in the VF(N)-76 newsletter of May 4, 1944:

> "In general, it may be stated that the prospects for the use of carrier-based night fighters are improving....The Commander, Task Group 58.1,["Jocko" Clark] on attaining flag rank and boarding the *Hornet*, brought Lieut. Reiserer's detachment with him from his previous command, the *Yorktown*."[73]

On August 17, 1944, the *Independence* joined Task Force 38 off Eniwetok with the Navy's first night air group, CVLG(N)-41. The formation of the night air group also spelled the end of the independent night fighter squadrons. Because the night fighters were concentrated in a single air group rather than into individual squadrons there were now night fighters in excess of fleet requirements. Admiral King decided to parcel them out in four-plane sections called Night Fighter Units(NFU). Each fighter squadron in the task force would gain one night fighter unit to fly night intercept missions. King

[73] VF(N)-76 Newsletter, May 4, 1944, BuAer Aircraft File, National Archives, Record Group 72, Box 1481.

also directed the decommissioning of all but a few night fighter squadrons to accomplish the redistribution.[74]

The independent night air group was effective in defeating the Japanese night air attacks. As the units gained experience they became a threat to any Japanese night activity. Lieutenant Commander R.J. McCullough, skipper of VF(N)-90 provided a thorough summary of his squadron's experiences during the Iwo Jima operation. He cited the breakdown of the radar automatic frequency control as the most common radar malfunction, and lauded the performance of the AN/APS-6A airborne intercept radar equipped Hellcats. He also requested removal of the AN/APS-4 equipped Hellcats. During the operation VF(N)-90 recorded 710 flights with 68 "duds" on the AN/APS-6A sets, while the older AN/APS-4's experienced 23 "duds."[75] Commander McCullough attributed the higher number of "duds" on the AN/APS-6A to its much higher usage rate. He also

[74] Rosenberg, 25. Aviation Planning Directive 82-A-44, September 20, 1944, CNO to Fleet Commanders and CNO message to CincPac and CincLant, October 7, 1944, BuAer Confidential Correspondence(now unclassified), National Archives, Record Group 72, Box 1454. Note: The *Independence* was an 11,000-ton light carrier, or CVL. TF 58 and TF 38 comprised the same ships, Admiral Nimitz rotated his key commanders and assigned different numbers as added security. When Admiral Spruance was in command, usually with Mitscher as Air Commander, it was called Fifth Fleet, and TF 58 respectively. When Admiral Halsey was in command, with Admiral J.S. "Slew" McCain as Air Commander, it was called Third Fleet and TF 38.

[75] "Duds" refers to radar malfunctions or complete breakdowns.

supported the continued use of rockets for "heckler" and strafing missions. He stated that the trajectory was the same as for the .50 caliber guns, but the rocket blast blinded the pilot and prevented him from observing rocket impact on target. McCullough's comments serve to underscore the amazing reliability and functionality of the airborne intercept radar sets, a tribute to the research, development, and production team.[76]

Okinawa was the last major operation for the maturing night fighter force. After a brief rest and refit at Ulithi Atoll, Task Force 58 sailed again on March 14, 1945, to support the initial assault on the largest of the Ryuku Islands, Okinawa. On March 17-18 the night fighters of the veteran VF(N)-90 began flying night patrol over the task force. The night Hellcats were successful in defeating several Japanese night bomber attacks. The increase in kamikaze attacks forced Admiral Spruance to keep Task Force 58 around Okinawa to support land operations. The night fighters continued night combat air patrol missions against Japanese forces on Okinawa and nearby islands. Japanese planes were more reluctant to engage the Americans at night. The Americans dealt heavy

[76] VF(N)-90 Summary, March 9, 1945, Naval Operational Archives, Night Aviation Operations File, Box 2.

losses to the Japanese air capability during the entire Okinawa operation. They also participated in night offensive attack and harassment missions further disrupting Japanese air operations while displaying the versatility of the carrier night fighter. After the Okinawa campaign, Japanese night air attacks dwindled to nothing; depleted of experienced pilots, as an air force ceased to be a threat to the fleet for the rest of the war.[77]

After the war the Japanese premier Tojo told General MacArthur that one of the three main factors in America's victory was the powerful fast carrier task forces. The carrier night fighters were an important member of the fast carrier team. By late 1943 the American Navy pilots were more experienced and flew aircraft that were superior to the Japanese aircraft. The Japanese began to exploit night air attacks during the first half of the war, but when the US Navy night fighters arrived they were able to effectively neutralize the Japanese night attacks.[78]

The carrier night fighter did not change American naval strategy in the Pacific Theater. Tactically, however,the night

---

[77] Aircraft Action Report, VF(N)-90 aboard USS *Enterprise*, March 17-18, 1945, Naval Operational Archives, Night Aviation Operations File, Box 2.

[78] Reynolds, 380.

fighters allowed the fast carriers to operate more freely. Prior to the arrival of the carrier night fighters, the fast carriers had to withdraw from the rest of the formation as a night defensive tactic.. The night fighters provided a freedom of movement which allowed task force commanders to deploy combat air patrols, both day and night, over all areas of operations. This extensive coverage protected ground troops from Japanese air attacks. Thus the contributions of the naval night fighters were significant as defensive fleet weapons.

In addition the night fighters added the dimension of night harassment attacks which augmented the offensive punch of the task force. The night fighters use in bad weather day missions further added to the air commander ability to provide a combat air patrol regardless of weather and protect the fleet. The carriers were the most important weapon in the Pacific Theater. Even if the night fighters saved only one or two carriers from attack during the war, their contribution would have been sufficient to justify the cost of their development.

The key to the successful performance of the naval night fighter hinged on the function and reliability of the radar system. The performance of the airborne radar set was exemplary, especially when one considers the difficult environment and the immaturity of the technology involved. But the technology that produced the system was far ahead of the technology required to make it reliable and durable.

During its operational life the AN/APS-4 and AN/APS-6(A) radar systems experienced numerous problems. Because of the environment and physical location of the radar set on carrier night fighters the biggest culprits were vibration and moisture. The big radial engine and the shock of landing on a carrier contributed most to the vibration problem. This vibration caused cracking of flexible waveguides, which rendered the automatic frequency control completely inoperable. The vibration also loosened tubes in all the components that caused a majority of airborne malfunctions.[79]

Carriers were nearly always at sea and the harsh salt air and moist conditions also contributed to radar problems. Moisture caused internal shorting in tubes and hastened corrosion in connector plugs. In addition to vibration and

---

[79] BuAer Technical Reports, Aeronautical Radio and Radar Laboratory, Philadelphia, November 26, 1945, National Archives, Record Group 72, Box 3.

moisture, cold temperatures at higher altitudes reduced performance on lubricants used on the scanner motors, thereby degrading radar performance.[80]

The AN/APS-4 radar set in particular suffered many radome failures. The AN/APS-4 radomes were made of resin-impregnated cloth. Rough handling by the deck crews often caused damage to these somewhat fragile radomes. Engineers at the Airborne Radio Research Laboratory at the Naval Aircraft Factory in Philadelphia developed a fiberglass radome that solved most of the radome failures. But they also discovered that the sturdier radome also attenuated the signal somewhat so they had to develop a honeycomb construction that sandwiched layers of polyfiber material between fiberglass layers giving good radio frequency energy transmission as well as good strength.[81]

The engineers and scientists responded quickly to the feedback from the operational and test units to correct the other problems. Westinghouse designed improved component chassis vibration dampers. Engineers at the Naval Research

[80] Letter from BuAer to BuShips, June 23, 1944, BuAer Confidential Correspondence, Volume III, National Archives, Record Group 72, Box 829. Letter from NRL to BuShips, May 27, 1944, BuAer Confidential Correspondence, Volume II, National Archives, Record Group 72, Box 829.

[81] Letter from BuAer to BuShips, January 13, 1944, BuShips Electronics Division General Correspondence, National Archives, Record Group 19, Box 146.

Laboratory tested several methods to reduce moisture intrusion and corrosion. They ordered the use of anodized connectors on all radar fittings to combat corrosion. They specified the use of the Dow-Corning Ignition Sealing Compound on all connector plugs to inhibit moisture intrusion. They also developed a sturdier radar pod sway brace made of chrome molybdenum to reduce breakage due to vibration.[82]

The first radar sets also suffered from poor production quality control as evidenced by the condition of new sets Westinghouse delivered to the Navy. Navy electronics technicians at NAS Floyd Bennett Field in Brooklyn prepared radar-equipped aircraft for delivery to fleet units. The technicians noted that almost every set required some minor adjustment or repair. Common production quality problems included crystals with improper ratios, wrong tubes installed, and bad or broken components. Naval Research Laboratory engineers worked closely with Westinghouse production managers to solve many of these problems.[83]

---

[82] Letter from BuAer to BuShips, March 25, 1944, BuShips Electronics Division General Correspondence, National Archives, Record Group 19, Box 146.

[83] Discrepancy Report NAS Floyd Bennett Field, November 1, 1944, BuAer Confidential Correspondence, Volume I, National Archives, Record Group 72, Box 830.

The pilots of the radar-equipped Hellcats and Corsairs provided vital information about radar performance in combat to these scientists. Many squadron after-action summaries included a separate entry about radar performance. The data helped engineers to concentrate on product improvements that would aid the combat pilot. During the war the Bureau of Aeronautics ordered over 2500 changes for the AN/APS-6 radar system alone. Despite this multitude of changes, squadron reliability statistics showed that the AN/APS-6(A) radar set was fully operational about 65-75% of the time. These are impressive statistics for such a complex and new system.[84]

The most prevalent problem the night fighters noted was the many automatic frequency control failures. The antenna was the next least reliable component. These components were the most complex parts of the system so their rate of failure was perhaps predictable. Both the manufacturers and Radiation Laboratory engineers spent a good amount of time attempting to

[84] Operations Summary, VF(N)-90, March 9, 1945, Naval Operational Archives, Night Aviation Operations File, Box 2. Addendum to Aircraft Action Report, VF(N)-90 aboard USS *Enterprise*, April 15, 1945, Naval Operational Archives, Night Aviation Operations File, Box 2. Operational Summary, VF(N)-90, January 23, 1945, Naval Operational Archives, Night Aviation Operations File, Box 2. Operations Summary, VF(N)-41, December 16, 1945, Naval Operational Archives, Night Aviation Operations File, Box 1. BuAer Engineering Division History, Radio and Electronics Branch, Radar Section, Part 7C, 8, National Archives, Record Group 72, Box 3.

solve these troublesome problems. These remained the primary shortcomings in the airborne intercept radar's reliability.

A study by Captain Charles F. Horne after the war revealed the following criticisms of the two night fighter radar systems:

> "...AN/APS-4 is satisfactory from an electrical point of view, except that the a quick-disconnect, moisture-proof plug should be incorporated at the wing-fold in cable #4 on all aircraft....The drag it[AN/APS-4] offers, and the wide range of speed through which it operates makes it very difficult to operate the aircraft as the trim controls must be worked "overtime"....AN/APS-6(A) has inadequate moisture proofing, faulty AFC function, poor beacon reception, excessive weight, and poor search presentation."[85]

Despite the problems exhibited by the radar sets, the night fighters were able to fly the majority of their missions with good, reliable equipment that gave them a distinct advantage over the enemy. When one considers the true immaturity of radar technology their performance is nothing short of extraordinary.

The identification system, however, did not enjoy the same success as the radar system. Repeated system failures and

---

[85] "Report of A Board Convened by the Commander in Chief U.S. Pacific Fleet, To Make Recommendations on Radar and Countermeasures Based on Experience in the War Which Resulted in the Defeat of Japan", December 3, 1945, Charles F. Horne, Captain, USN Chairman, Naval Operational Archives, Personal History File of Charles F. Horne.

false indications continued to plague the system. While the "Black Maria" modification did improve the system reliability, IFF was not completely effective in allowing pilots or anti-aircraft gunners to open fire on radar targets without visual identification. The technology to make these identification systems reliable was not within the grasp of the scientists and engineers. Indeed no other nation successfully developed a superior type of identification system for their aircraft. These systems require exact frequency matching and timing to give accurate indications. Judging from the number of friendly fire incidents in recent years, identification friend or foe systems still exhibit some of the same shortcomings.[86]

Conclusion

The threat of enemy air attack at night was the original impetus for the development of radar and the night fighter. The British had demonstrated the feasibility of airborne radar and the potential for night fighters to counter night bombing attacks during the Battle of Britain. Even before the war with Japan erupted, the United States Navy foresaw the necessity of carrier-borne protection for the fleet from night air attacks.

[86] Office of Naval Intelligence Report from NavAir Attaché London, May 18, 1945, National Archives, Record Group 38, Box 20. Guerlac, 373-374.

Design limitations of the existing carriers and aircraft dictated a radar system small and light enough to fit on a single-seat fighter. Besides being light and compact it would have to have simplified operation so that the pilot could operate it with a minimum of distraction away from the flight controls.

The close cooperation of the Radiation Laboratory, the Naval Research Laboratory, and aircraft and electronic contractor scientists and engineers along with the contributions of the British Technical Mission were the keys to the success in developing the microwave airborne intercept radar systems. The Radiation Laboratory had the best scientific minds in America working on the project and as Dr. Guilmartin pointed out to me, his own research on technology in World War II revealed that the United States had a distinct advantage in the depth and breadth of scientific and engineering talent, an advantage that was unmatched by any other nation. At the Massachusetts Institute of Technology and other colleges and universities around the country, scientists, and engineers solved the multitude of problems and developed the microwave airborne intercept radar set. The incredible pace of development of the AN/APS-4 and AN/APS-6 airborne

intercept radar sets illustrates the outstanding cooperation between the civilian scientists, contractors, and the military. Without this cooperation an effective set could not have been developed and produced in such a short time. Walter Millis sums up their contribution:

> But in the Second World War, to a far greater extent than ever before, the scientist, the engineer and the technologist were harnessed directly to the conduct of the struggle; the "battle of the drawing boards" was no empty metaphor when a battle of blood and bullets only a few months later might turn upon the battlefield be related so closely to the success or failure of the designers, researchers and inventors.[87]

The performance of the naval night fighter in the war was exemplary. The Navy developed flying and night interception techniques almost from scratch. Because of the pressing need for night fighters in the Pacific the training course for the night fighter was short. The Quonset Point syllabus listed only 14 hours dedicated to night radar tactics of the 56 hour night training hours.[88] Despite limited training time and equipment; the night fighters became a formidable weapon by the end of hostilities. Admiral McCain, Air Commander of Task

---

[87] Walter Millis, *Arms and Men: A Study in American Military History*, (New York: G. P. Putnam and Sons, 1956), 293.

[88] Report of Progress Field Visit, April 30-May 5, 1945, BuAer Progress Division History, Part 3, National Archives, Record Group 72, Box 14.

Force 38, paid tribute to the night fighter's contribution in his last after action report which stated:

> No efforts were made by the Japanese to attack our forces at night even though our location was known, even though the Japanese had many planes within range, and even though they had many suicide-bound pilots wanting nothing more than to crash their planes into our major units. During the entire time that Task Force 38 operated off Japan, no Japanese attacked these forces at night.[89]

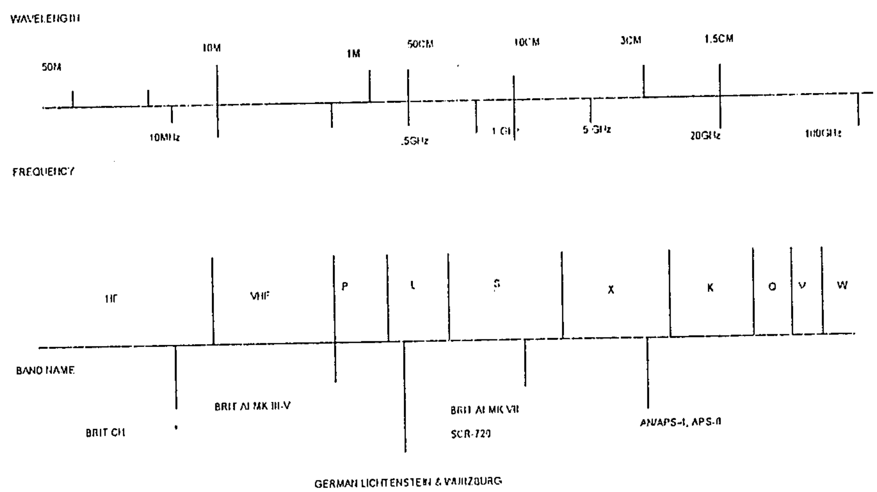
While the naval night fighter did not alter the strategy or hasten the end of the war, it did indeed make a significant contribution to future of American fighter designs. From 1945 onward, American fighter aircraft have been equipped with microwave radar. From Korea to Desert Storm, American radar-equipped, single-seat fighter aircraft have dominated their opponents. American defense contractors and military scientists developed more powerful airborne intercept radar and radar-guided missiles which increased the lethality of the fighter aircraft. In fact many of the current combat aircraft have been designed around the radar package. The F-15 Eagle and F-14 Tomcat are but two examples of this. Today's all-weather single-seat fighters form the bulk of American tactical and strategic air power. Powerful turbofan-powered fighters have radar systems that are capable of detecting targets over

[89] James Seton Gray, Jr., "Development of Naval Night Fighters in World War II", *United States Naval Institute Proceedings* (July 1948): 851.

100 miles distant. They can carry payloads equal to that of the World War II B-17 and fly at twice the speed of sound. Tracing the development of the American fighter, the origins of today's fighter began with the naval night fighter, the first high performance single-seat aircraft with microwave radar. The outstanding work and cooperation of the many scientists and engineers enabled the naval aviator to go confidently and boldly into the night.

Appendix A

Radar Frequency and Wavelength Chart[90]



90 Data from Gunston, 40.

LIST OF REFERENCES

Secondary Materials

World War II

Belote, James H. and William H. Belote. *Titans of the Seas: The Development and Operations of Japanese and American Carrier Task Forces During World War II*. New York: Harper and Row, 1975.

Dull, Paul S. *A Battle History of The Imperial Japanese Navy, (1941-1945)*. Annapolis: Naval Institute Press, 1978.

Millett, Alan R. and Peter Maslowski. *For the Common Defense: A Military History of the United States of America*. New York: The Free Press, 1984.

Millis, Walter. *Arms and Men: A Study in American Military History*. New York: G.P. Putnam and Sons, 1956.

Morison, Samuel Eliot. *The Two-Ocean War: A Short History of the United States Navy in the Second World War*. Boston: Little, Brown and Company, 1963.

_______, *History of United States Naval Operations in World War Two, Volume VII, Aleutians, Gilberts and Marshalls.* Boston: Little, Brown and Company, 1951.

_______, *History of United States Naval Operations in World War Two, Volume XII, Leyte: June 1944-January 1945*. Boston: Little, Brown and Company, 1958.

_______, *History of United States Naval Operations in World War Two, Volume XIII, The Liberation of the Philippines: Luzon, Mindanao, the Visayas, 1944-1945*. Boston: Little, Brown and Company, 1959.

_______, *History of United States Naval Operations in World War Two, Volume XIV, Victory in the Pacific: 1945*. Boston: Little, Brown and Company, 1960.

Reynolds, Clark G. *Fast Carriers: The Forging of an Air Navy*. New York: McGraw-Hill, 1968.

Spector, Ronald H. *Eagle Against the Sun: The American War with Japan*. New York: Vintage Books, 1985.

Aviation

Aders, Gebhard. *History of the German Night Fighter Force 1917-1945*. Translated by Alex Vanags-Baginski and Brendan Gallagher. London: Jane's Publishing Company, 1979.

Brown, Eric Melrose. *Duels in the Sky: World War II Naval Aircraft in Combat*. Annapolis: Naval Institute Press, 1988.

_______, *Wings of the Navy: Flying Allied Carrier Aircraft of World War Two*. London: Jane's Publishing Company, 1980.

Francillon, Rene J. *Japanese Aircraft of the Pacific War*. London: Putnam Aeronautical Books, 1987; reprint, Annapolis: Naval Institute Press, 1994.

Green, William. *Famous Fighters of the Second World War, Volume Two*. New York: Doubleday & Company, 1962.

Gunston, Bill. *Night Fighters: A Development & Combat History*. New York: Charles Scribner's Sons, 1976.

Jane's Publishing Company. Jane's Fighting Aircraft of World War II. London: Jane's Publishing Company, 1945-46; reprint, New York: Crescent Books, 1992.

Mersky, Peter B. *U.S. Marine Corps Aviation: 1912 to the Present*. Annapolis: The Nautical & Aviation Publishing Company of America, 1983.

Roscoe, Theodore. *On the Seas and in the Skies: A History of the US Navy's Air Power*. New York: Hawthorn Books, 1970.

Sherry, Michael S. *The Rise of American Air Power: The Creation of Armageddon*. New Haven: Yale University Press, 1987.

Swanborough, Gordon and Peter M. Bowers. *United States Navy Aircraft Since 1911*. London: Putnam & Company Limited, 1976.

Wright, Monte Duane. *Most Probable Position: A History of Aerial Navigation*. Lawrence, KS: University Press of Kansas, 1972.

Radar

Allison, David Kite. *New Eye for the Navy: The Origin of Radar at the Naval Research Laboratory*. Washington: Government Printing Office, 1981.

Devereux, Tony. *Messenger Gods of Battle: Radio, Radar, Sonar: The Story of Electronics in War*. London: Brasseys, 1991.

Fisher, David E. *A Race on the Edge of Time: Radar--The Decisive Weapon of World War II*. New York: McGraw-Hill, 1988

Lovell, Bernard. *Echoes of War: The Story of H_2S Radar*. Bristol, UK: Adam Hilger, 1991.

Swords, Sean.S. *Technical History of the Beginnings of Radar*. London: Peter Peregrinus Ltd., 1986.

Zahl, Harold A. *Radar Spelled Backwards*. New York: Vantage Press, 1972.

Technology

Baily, Charles M. *Faint Praise: American Tanks and Tank Destroyers during World War II*. Hamden, CT: Archon Books, 1983.

Baxter III, James Phinney. *Scientists Against Time*. Boston: Little, Brown and Company, 1946.

Constant, Edward W. *The Origins of the Turbojet Revolution*. Baltimore: The John Hopkins University Press, 1980.

Vincenti, Walter G. *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*. Baltimore: The John Hopkins University Press, 1990.

Zuckerman, Solly. *Scientists and War: The Impact of Science on Military and Civil Affairs*. New York: Harper & Row, 1967.

Unpublished Works

Rosenberg, David Alan, "The Black Chickens: The Story of the Pioneer Navy Night Fighter Squadrons in World War Two." Undergraduate composition, American University, 1967.

University of Pittsburgh Historical Staff at the Office of Naval Research. *The History of United States Naval Research and Development in World War II*. 1950. Navy Operational Archives, Box 374.

Primary Source Material

Published Works

Bowen, E.G. *Radar Days*. Bristol, UK: Adam Hilger, 1987.

Boyce, Joseph C. ed. *New Weapons for Air Warfare: Fire Control Equipment, Proximity Fuzes, and Guided Missiles*. Boston: Little, Brown and Company, 1947.

Clark, J.J and Clark G. Reynolds. *Carrier Admiral*. New York: David McKay Company, 1967.

Gray, James Seton, Jr. "Development of Naval Night Fighters in World War II." *United States Naval Institute Proceedings* (July 1948): 847-851.

Guerlac, Henry E. *The History of Modern Physics 1800-1950 Volume 8: Radar in World War II*. Boston: American Institute of Physics, 1987.

Martin, William I. "Night is My Ally." In *Carrier Warfare in the Pacific: An Oral History Collection*, ed. E.T. Woolridge, 144-152. Washington: Smithsonian, 1993.

Rowland, Buford and William Boyd. *US Navy Bureau of Ordnance in World War II*. Washington: Government Printing Office, 1954.

Stafford, Edward P. *The Big E: The Story of the USS Enterprise*. New York: Random House, 1962.

Government Documents

United States, Department of the Navy, Bureau of Aeronautics, General Correspondence File, Record Group 72, Boxes 1, 22, 49, and 50, National Archives, Washington, DC.

United States, Department of the Navy, Bureau of Aeronautics, Aircraft File, Record Group 72, Boxes 1481 and 1485, National Archives, Washington, DC.

United States, Department of the Navy, Bureau of Aeronautics, Division History Files, Record Group 72, Boxes 2-5 and 10-14, National Archives, Washington, DC.

United States, Department of the Navy, Bureau of Aeronautics, Secret Correspondence File, Record Group 19, Box 3, National Archives, Washington, DC.

United States, Department of the Navy, Bureau of Aeronautics, Confidential Correspondence File, Record Group 72, Boxes 287, 829, 830, and 1454, National Archives, Washington, DC.

United States, Department of the Navy, Bureau of Ships, General Correspondence, Record Group 19, Boxes 60 and 146, National Archives, Washington, DC.

United States, Department of the Navy, Office of Naval Intelligence, Confidential Messages from ComNavEu, Record Group 38, Boxes 20, 21, and 56, National Archives, Washington, DC.

United States, Department of the Navy, Naval Research Laboratory, General Files, Record Group 19, Box 22, National Archives, Washington, DC.

United States, Department of the Navy, Night Aviation Operations File, Boxes 1 and 2, Naval Operational Archives, Washington, DC.

United States, Department of the Navy, Personal History File of Charles F. Horne, Naval Operational Archives, Washington, DC.